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DEVELOPMENT OF THE BASIC FLIGHT INSTRUCTION TUTORING SYSTEM (BFITS)

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The Basic Flight Instruction Tutoring System (BFITS) is a microcomputer-based flight trainer designed to teach both the declarative and procedural knowledge needed for basic flight maneuvers, while monitoring, tracking, and recording the student's behavior as he/she works with the tutor. BFITS provides a criterion task for (a) the validation of experimental psychological tests under consideration for pilot selection, and (b) the evaluation of the effects of drugs and environmental factors on pilot performance. BFITS consists of an instructional module, a flight simulator, and a performance evaluator, which work together to involve the student in tasks requiring both cognitive and psychomotor skills. The instructional module teaches the declarative knowledge of basic flight using text, graphics, and animation. The flight simulator provides the student with practice in flying a simulated airplane. It is used in conjunction with a number of easily changed flight scenarios that direct the student's current task and provide performance evaluation criteria and hint messages. The performance evaluator tracks student progress and allows the student to view a graphical display of his/her performance as measured against the evaluation criteria. Flights can be played back for review also.

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PREFACE

This paper reports the results of work completed under Contract # F33615-89-C-0009, awarded in response to a Phase 2 SBIR proposal titled "Development of the BFITS Intelligent Tutoring System." This is the third and final report relating to this overall effort. A prototype system was developed during the Phase 1 effort which became known as the "Basic Flight Instruction Tutoring System," or BFITS for short. Prior to Phase 2 of this effort, an interim effort was performed which primarily focused on specification of systems and courseware to be developed during Phase 2 of the BFITS development effort.

DEVELOPMENT OF THE BASIC FLIGHT INSTRUCTION TUTORING SYSTEM (BFITS)

SUMMARY

The Basic Flight Instruction Tutoring System (BFITS) was developed to support the research mission of the Learning Abilities Measurement Program (LAMP). Toward that end, BFITS teaches both the *what* and *how* of basic flight, while monitoring, tracking, and recording the student's behavior as he/she works with the tutor. The results of studies using BFITS will enable LAMP researchers to make informed recommendations leading to improved personnel selection and classification methods for the Air Force.

BFITS consists of an instructional module, a flight simulator, and a performance evaluator. Each of these modules work together to involve the student in tasks requiring both cognitive and psychomotor (hand-eye-foot coordination) skills. The instructional module teaches the *what* of basic flight using text, graphics, and animation. The flight simulator provides the student with a hands on experience of the *how* of flying a small airplane. It is used in conjunction with a number of easily changed flight scenarios that direct the student's current task and provide performance evaluation criteria and hint messages. The performance evaluator tracks student progress and allows the student to view a graphical display of his/her performance as measured against the evaluation criteria. It also provides the student with the option of viewing the just completed flight, and with review messages indicating the areas where the evaluation criteria were exceeded.

BFITS is a powerful and flexible research tool with great potential. Its use will determine its validity as an indicator of learning ability. Future developments could include voice feedback, diagnostic feedback after each practice flight, and more powerful authoring tools. BFITS could also be used in new applications such as assessing the effects of drugs, stress, or other environmental factors on pilot performance.

INTRODUCTION

LAMP and BFITS

In this report, we describe the development of the Basic Flight Instruction Tutoring System (BFITS). BFITS was developed in support of the research mission of the Learning Abilities Measurement Program (LAMP). The mission of LAMP is (a) to identify through basic research the cognitive abilities that enable students to acquire knowledge and skills, and (b) develop and validate computer-based tests of these abilities. The ultimate goal is to use this computer-based cognitive ability measurement (CAM) technology to improve personnel selection and classification in the Air Force.

LAMP has two major activities. One is basic research on learning and cognition which leads to the development of CAM tests. The second is the validation of these CAM tests as predictors of complex skill acquisition. To accomplish this second goal, LAMP researchers have developed computer-based learning environments designed for complex learning assessment (CLASS). Learning environments have been developed to deliver instruction in Pascal programming (Shute & Kyllonen, 1990), basic electricity (Shute, 1990), and flight engineering. In each case, the learning environment has been designed to record various learning measurements as the student progresses through the course and to assess learning outcomes at the end of instruction.

BFITS was designed with these same goals in mind. It provides a means for observing and tracking the behavior of students as they attempt to learn basic flight procedures. Designed to teach both the *what* and the *how* of basic flight, BFITS also records data during (a) the initial presentation of concepts and principles, and (b) the practice phase in which students apply and refine their knowledge in flight training sessions using the BFITS simulator. BFITS will provide a special benefit in that it will link LAMP to the aircrew selection and classification function within the Armstrong Laboratory. As a result of studies with BFITS, LAMP researchers will be able to make informed recommendations for new tests to be included in a future generation of the Basic Attributes Test used for aircrew selection and classification.

Background

Research and development on pilot selection and training began to receive emphasis during World War II (Koonce, 1984). One concern motivating training research was the safety of flight during the early learning stages. The early flight simulators of the 1930's and 1940's were crude and low in fidelity by present-day standards, but were a help nonetheless. The war effort brought increased emphasis on the quality and availability of simulators, but their expense also increased dramatically. In the 1960's, flight simulators started to utilize analog and digital computers for flight equations, handling qualities, motion systems, and visual scene generation (Koonce, 1976). However, they became too expensive for operational use in selection of flight training candidates (Hopkins, 1975).

Since the 1970's the Air Force has conducted research on the use of computers in the selection of flight training applicants. This work has taken two approaches. One approach was to use performance measures recorded on examinees operating a flight simulator in a type of job sample test. One early project using GAT-1 flight trainers and a Varian computer was designed to measure the applicant's performance as he was taught basic flight maneuvers and how to fly a basic traffic pattern (Long & Varney, 1975). This system, the Automated Pilot Aptitude Measurement System (APAMS), was intended to reduce the cost of pilot training by eliminating the Flight Instruction Program that used real aircraft. The system was expensive and measured over 170 variables. The resulting regression equation was massive and difficult to cross-validate.

One predictor measured by APAMS, two-axis tracking skill, has subsequently been shown to account for a large part of the variance in pilot training performance as indicated by pass/fail and overall class standing. This relationship has been found in research at US Air Force

Academy (Koonce, 1978), the Air Force Human Resources Laboratory (Bordelon & Kantor, 1986), and the Naval Aerospace Medical Research Laboratory (Griffin & Koonce, 1991).

The second approach applied to computerized measurement in pilot selection uses the computer to measure basic information-processing abilities. The first effort of this type in the Air Force was by Pew, Rollins, Jager-Adams, and Gray (1977). This group assembled a battery of eight information-processing tasks and a job sample consisting of measures taken from a flight simulator. The resulting regression equation comprised 15 variables including the job sample and accounted for about 27% of the variance in contact check ride scores. Various tasks contributed to the equation. Subsequently, Imhoff and Levine (1981) published a set of recommended tasks for pilot selection. The Basic Attributes Test (BAT) has evolved from these early efforts (Carretta, 1987). The BAT effort has been concerned with developing a computer-based battery of basic cognitive, perceptual, and psychomotor tasks, and personality measures that supplement to the Air Force Officer Qualifying Test (AFOQT) in predicting undergraduate pilot training (UPT) outcomes. Carretta (1989) reported that a model which combines AFOQT and BAT variables accounted for 19% of the variance in UPT pass/fail.

Perhaps the best way to view BFITS is as a third approach to using computerized measurement in pilot selection. BFITS was not designed to measure basic abilities, nor was it designed to measure flying aptitude with a type of job-sample approach. Instead, BFITS was designed to give a detailed picture of the process by which naive learners acquire the skill of flying a simulated general aviation aircraft. In this case, the depiction of the skill acquisition process would need to be quantitative. A key component in the conceptual design of BFITS was the selection of performance measures that should be recorded during instruction and practice. These performance measures would be used as dependent variables in subsequent validation studies of basic cognitive ability tests developed by LAMP.

THE DESIGN AND DEVELOPMENT OF BFITS

Overview of BFITS

BFITS design was driven in part by recent developments in cognitive psychology concerning the acquisition of skill. The acquisition of most complex skills typically proceeds through three stages (Anderson, 1983): a declarative stage in which the learner acquires the basic concepts and principles underlying skilled performance; a procedural stage in which the declarative knowledge becomes compiled into a more easily applied form and the errors in the initial understanding of the task are gradually detected and then eliminated through practice; and an autonomous stage in which task performance gradually becomes more refined, faster, and less attention-demanding with continued practice. In keeping with this view of skill development, a basic flight procedures tutor should teach a subset of the basic concepts and principles of flying (declarative stage) and then provide the opportunity to practice the application of these in the flight simulator component of the tutor (procedural stage). The tutor should be designed to assess the learner's knowledge and skill at several points in the learning process.

In what follows, the three components or modules comprising BFITS are briefly described. Subsequent sections will describe these in more detail.

The Instructor Module

The instructor's main purpose is to manage the process of teaching the declarative knowledge underlying basic flight. It presents the student with logical blocks of information. The content of the blocks can be any combination of text, graphics, and animation. The instructor also handles testing, review of information, and student progress through the tutorial. Various options such as back-paging through a lesson, reviewing previously completed lessons, and allowing the student to quit in the middle of a lesson are configurable.

The Simulator Module

The BFITS simulator is designed to model the flight characteristics of a small single-engine airplane. It teaches the *how* of basic flight, and can be used to demonstrate and practice a number of flight maneuvers from simple climbs and descents to more complex maneuvers such as crosswind landings. The simulator is controlled with a joystick and rudder pedals. These are connected to a game card installed in an IBM or compatible PC. The simulator provides a graphical representation of the airplane's control panel, as well as an out-the-window view. An EGA video card and a math coprocessor are required. The simulator works in conjunction with the performance evaluator module.

The Performance Evaluator Module

The performance evaluator works in concert with the flight simulator. It is responsible for establishing a flight's initial conditions, such as altitude and airspeed. It tracks the student's performance relative to predefined criteria, and lets the student know (in the form of hint messages) how the current flight measures up to the established criteria. Once a flight has been completed, the evaluator determines the student's pass/fail status, and then gives the student the option of viewing a graphical display of his/her performance. The student also has the option of replaying the flight. During a flight replay, the evaluator lets the student know when the pass/fail criteria have been exceeded. Finally, the performance evaluator has the job of saving to disk all data relevant to a flight. These data can be used to replay the student's flight(s), and can be imported into a statistical package for detailed analysis.

Research Basis of Performance Criteria

Performance measurement in BFITS is based on the principles of criterion-referenced testing (Nitko, 1980). This means that the students continue to perform the task until attaining the desired level of proficiency. The criteria to which a students' performance is referenced can be determined empirically or taken from established sources.

In the BFITS program, most of the criteria were taken from the Federal Aviation Administration (FAA) Practical Test Standards (PTS) for pilots seeking a single-engine airplane pilot's certificate (FAA, 1988). In the PTS, the FAA also states tolerances for desired performance of specific flight parameters in the various maneuvers. Some variables that BFITS monitors and scores are not specified in the PTS, but are taken from prior research by Koonce (1979, 1987). The tolerances used by Koonce, Gold, & Moroze (1986) were developed from the data of over 300 Air Force Academy Cadets performing basic flight maneuvers and then taking 50% of the magnitude of the standard deviation of the performance errors on each of the monitored flight variables as the tolerance limits.

In the performance of turns, climbs, and other dynamic maneuvers, some of the criterion variables that are monitored and subsequently evaluated may not be constant throughout. For example, to begin a turn, the wings should be level and the heading stable. When the turn is started, there is a period of time in which the bank angle is transitioning from zero to the desired bank angle, such as 30 degrees. During the transition into a turn, the bank angle is not scored. But after reaching a certain point the bank angle should be established and evaluated. A logic system had to be developed to determine just when to score and not to score these variables that are supposed to have constant values at some times and not at other times.

The transition logic used by BFITS was determined by a margin of at least 50% over the general rules-of-thumb used in the performance of the maneuvers. For example, the rules or guidelines for rolling out of turns is that they should be started at approximately one-half of the bank angle's degrees prior to the desired heading. There are similar rules-of -thumb for other flight maneuvers.

The number of trials that it takes a subject to perform specific tasks within tolerances to preset criteria has been found to be a rather stable measure of performance (Koonce, 1978) and useful in the prediction of success in training systems that are heavily dependent on students acquiring certain skills within fixed time constraints (Griffin and Koonce, 1991). In military flight training environments, student pilots are expected to complete various phases of their flight training within set numbers of flight hours. Failure to do so results in a review flight and possible termination from the program. Thus, one can say that the rate of acquisition of the flight training skills might be a criterion that pilot selection programs are really trying to predict.

As a research instrument, BFITS provides the researcher with the numbers of trials that the students needed to achieve the criterion level of performance on each flight task. Also, in using trials to criterion, one can be confident that subjects are at similar levels of skill as they progress from basic flight tasks to advanced flight tasks because one must demonstrate a certain skill level before progressing to the next level of difficulty.

Instructor and Performance Evaluator Design

Syllabus Development

A Basic Flight Instruction Syllabus was developed covering the fundamental skills required to pilot an airplane. This syllabus is the result of an analysis of the training requirements appropriate to fulfill the primary and secondary BFITS requirements, which are the creation of research data and the instruction of students. It was assumed that the students working with BFITS would have the basic intellectual and perceptual-motor skills required for acceptance to a pilot training program: a high school education, a desire to fly airplanes, and no perceptual-motor difficulties. The students may be completely naive regarding airplanes and the theory of flight.

The topics covered by BFITS are a subset of those typically covered in flight training courses as described by the FAA Flight Training Handbook (1980), the Private Pilot Training Syllabus (Jeppesen-Sanderson, 1988), and the University of Illinois' Institute of Aviation Basic Flight Instruction Training Syllabus (1989). The topics begin with fundamental concepts and build up to more complex topics. Ground school and flight training programs in general proceed in this manner so that the student always has some foundation for the next topic in the sequence. With this building blocks approach "... a student can master the segments of the overall pilot performance requirements individually and can progressively combine these with other related segments until their sum meets the final objective." (FAA, 1977, AC 60-14, p. 78). This is the general approach that was taken in determining the sequence of the lesson materials and skills development required by BFITS.

The syllabus is based upon a careful analysis of the knowledge and skills required for the safe flying of an airplane. The lesson objectives are oriented toward the development of knowledge (declarative stage), increased understanding of knowledge through application (procedural stage), translation of knowledge to perceptual-motor tasks (procedural stage) and development of skills to preset criterion levels (autonomous stage). The lesson materials are sequenced from the most basic and fundamental concepts (building blocks) to the more complex ones that are dependent upon the earlier materials.

The BFITS syllabus aims to teach a subject the basic principles of flying an airplane. This includes presentations on the principles of flight, the parts of an airplane, and how the airplane is controlled in flight. Following the development of basic declarative knowledge, the student is taught how to fly the airplane (simulator). The flight instruction portion includes knowledge development regarding the maneuvers to be performed in the current lesson as well as instruction and a demonstration on how to perform the maneuvers. The flight instruction proceeds from very basic maneuvers through the complex task of performing takeoffs and landings in the presence of crosswinds.

BFITS proceeds from basic flying skills through the performance of traffic patterns (takeoff to landing). Many topics that are not germane to these goals, although usually taught in flight schools, are not included in the BFITS syllabus. These include, but are not limited to: Required

Certificates & Documents, Weight & Balance, Checklist Usage, Preflight Inspection, Detailed Engine Operations, Radio Communications, Emergency Procedures, Cross-Country Procedures and Techniques, Night Flying, and Meteorology. Some of these items could easily be incorporated into the syllabus but are not directly relevant to the BFITS research mission. Of course, a complete pilot training program would include all of the above plus physiological factors associated with flight and other topics.

Some of the topics covered by BFITS can be approached in several different ways. The approach is generally determined by the individual instructor, his or her own conceptions, and experience in teaching students about flying. The order of topics in BFITS was based on our subject matter expert's (SME's) experience and consideration of materials published by the FAA (AC 60-14, AC 61-21A, AC 61-23B, and the practical test standards for private pilot certification), training course outlines (TCOs) approved by the FAA for flight schools, several flight instruction textbooks, and the materials of several companies who distribute flight training materials.

The initial syllabus consisted of three lessons concerned with the development of knowledge (declarative stage) and nineteen lessons involving the development of both knowledge and flying skills. As Phase II of the effort progressed, we realized that the first three lessons would be too demanding on the students having no prior knowledge of flying; so, the three lessons were divided into nine lessons. The flight lessons were increased by three, from nineteen to twenty-two.

The first nine lessons develop the concepts of how airplanes fly, the parts of an airplane, and what the pilot needs to do to fly an airplane. The remaining lessons present demonstrations of maneuvers to students and provide guided practice opportunities (see Table 1).

The BFITS lesson plan is appropriate to BFITS simulation capabilities while covering a large portion of the entire basic flight training spectrum. More importantly, it will create a wide range of data sets for use in research, varying from simple response time arrays to multiple variable sets acquired during the execution of complex multiple task-loaded procedures.

Instructional Methodology

Our selection of training methodologies was influenced by two factors, training effectiveness and suitability for research purposes. The training goal of BFITS is to develop the individual's skill in flying the BFITS simulator through a required scenario of maneuvers, and to maximize the transfer of skills to a real training aircraft. The research goal of BFITS is to collect useful and accurate data relating to the acquisition of flight skills.

The approach taken in the development of this syllabus and in the planning of the instructional and evaluation techniques involved integration of principles and techniques expressed in FAA's Aviation Instructor's Handbook (AC 60-14, 1977), the U. S. Air Force's Principles and Techniques of Instruction (AFM 50-9), Principles of Instructional Design by Gagne and Briggs (1979), the Aircraft Owners and Pilots Association's

Table 1. BFITS Syllabus

Knowledge (Declarative Stage)

1 Introduction and principles of lift and airfoils
2 Anatomy of an airplane
3 The axes of flight and movement about them
4 Airplane control surfaces
5 Other controls
6 Basic four forces acting upon the airplane
7 Other forces acting on the airplane
8 Cockpit displays
9 Response of the instruments to the control inputs and the resulting effects on the airplane

Flight Skills (Procedural Stage)

Block I (Basic Flight Procedures):
10 Climbs, descents, leveloffs, and cruise
11 Shallow and medium banked turns
12 Climbing and descending turns
13 Airspeed transitions
14 Review test lesson

Block II (Stall-Related Maneuvers):
15 Introduction to slow flight (no flight tasks)
16 Slow flight and stall recovery
17 Landing and takeoff stalls
18 Steep turns
19 Accelerated stalls
20 Review test lesson

Block III (Ground Referenced Maneuvers):
21 Rectangular patterns with and without winds
22 Turns about a point, with and without wind
23 Introduction to traffic patterns (no flight tasks)
24 Takeoff, upwind, crosswind, & turn downwind
25 Downwind, base, and final
26 Flare and landings - no wind
27 Go-around
28 Complete traffic pattern - no wind
29 Crosswind takeoff and landing
30 Complete traffic pattern with crosswind
31 Review test lesson

Flight Instructor's Flight/Ground Instructor Course (undated), and the Basic Flight Training Syllabus (University of Illinois Institute of Aviation, 1989).

The format used for the first nine lessons is to give (a) a brief overview of the current lesson's topic, (b) a review of the material presented in the previous lesson(s) that would be useful in the current lesson, (c) presentation of the lesson with review questions on each major topic covered, (d) a summary of the lesson just covered and a brief overview of the topic(s) to be presented in the next lesson, and (e) a test covering the entire lesson and feedback on the test results.

Beginning with Lesson 10, BFITS presents a demonstration of the maneuvers that the student is to perform for that lesson. This occurs immediately after the comprehension test and feedback. The student then practices the maneuvers until reaching the criterion level of performance.

Three of the lessons, 14, 20 and 31, are simulator flight tests in which the students are asked to perform certain maneuvers that had been learned to a criterion level of performance. These flight tests measure retention of previously learned flight simulator skills.

Lessons follow a pattern (see Figure 1). Each begins with a brief overview of the current lesson. This is followed by a review of concepts and skills relevant to the current task that were learned in the previous lesson. When the student finishes the review, the lesson presentation begins. Lesson presentation is structured such that the student is introduced to new material in logical units, or blocks of frames. Most lessons consist of several blocks, so, BFITS presents a brief question after each block of information. The question samples the student's knowledge of the material just covered. If the student responds correctly, the program presents the next lesson block. If the question is answered incorrectly, BFITS repeats the relevant frames, highlighting (in yellow typeface) pertinent information and skipping any areas which do not apply to the question. If the question is incorrectly answered a second time, then the student is given an explanation of why the answers were not correct. Likewise, a complete explanation of the correct answer is given.

At the end of each lesson, there is a quiz (typically 10 questions) covering the material just presented. After completing a quiz, the student is given a second opportunity to answer the incorrectly answered questions. The format followed is similar to that at the end of the block presentations.

The materials are presented in a manner that is both interesting and motivating. Each of the general topical areas is broken into smaller blocks or lessons in which specific concepts are presented and skills practiced until satisfactorily. Each simple task is performed satisfactorily before the next learning task is introduced. Lessons are brief to minimize the probability of answering test items incorrectly, while still keeping students active, involved, and sufficiently challenged. When a question is not answered correctly, a review of relevant material is presented, and if further difficulty is encountered the system explains the reasoning behind both incorrect and correct answers. Helpful feedback is provided to maintain a positive attitude in the students, and to help reinforce the student's memory for the concept or fact being taught.

Questions in the lesson quizzes are designed to assess (a) the student's comprehension and retention of the information presented in the lesson (discriminations and concrete concepts), and (b) his/her ability

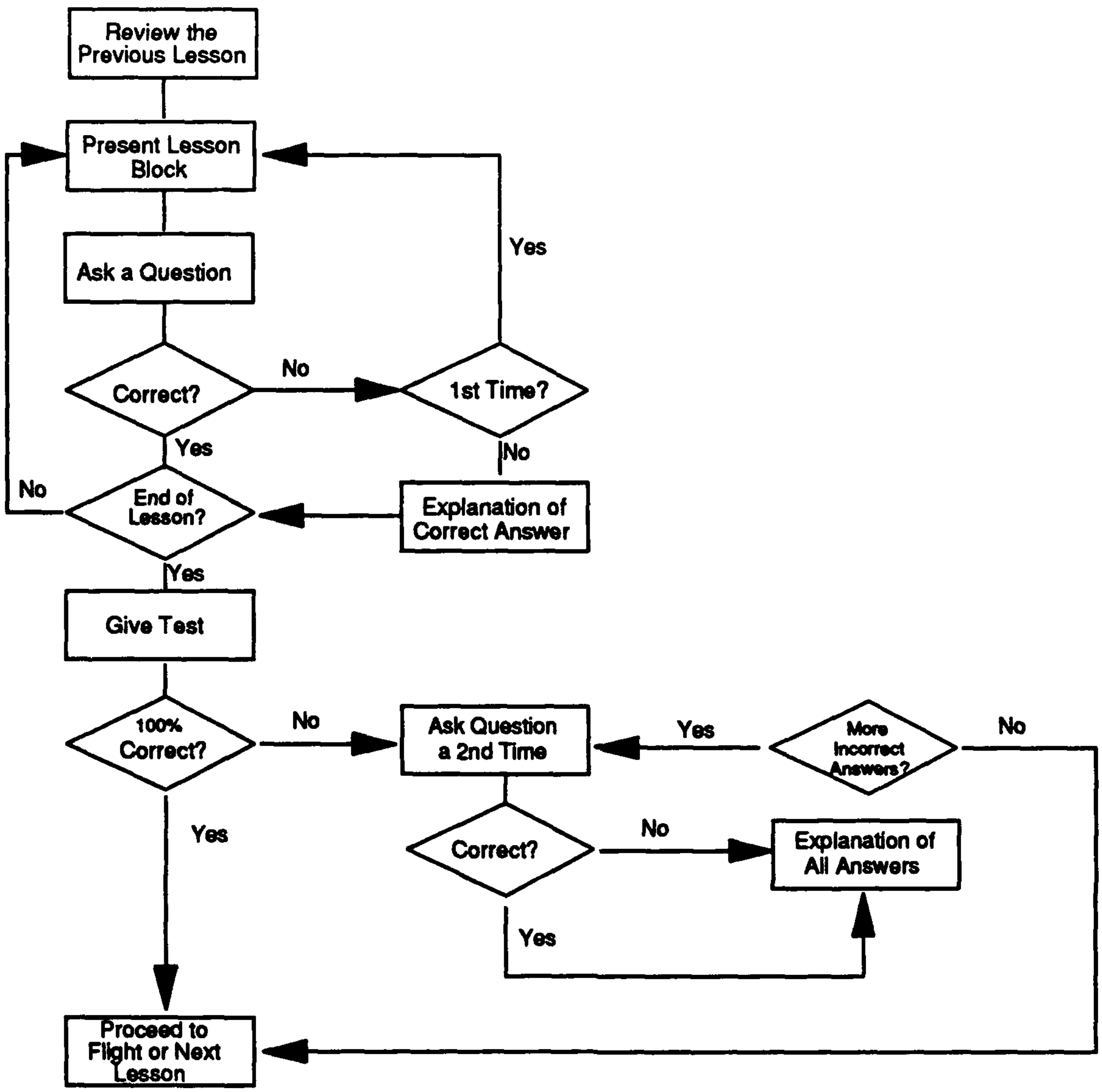


Figure 1. Lesson Flow

to apply the concepts learned to different situations (rule understanding and application). These application questions and the practice of the maneuvers may be thought of as opportunities to observe the student in near-transfer conditions, success in which would reflect a more sophisticated state of knowledge development.

Lessons 10 through 31 include the development of motor skills as well as intellectual skills, and therefore include the measurement of perceptual-motor ability, including an assessment of the rate of skill acquisition. Learning to perform the motor skills involved in controlling an airplane entails several components. In any given maneuver the student must learn to attend to the appropriate stimuli, perceive their significance with respect to a goal, note discrepancies between the stimuli and the desired state, and make the necessary corrections. For example, in executing a 45 degree right turn at 80 miles per hour, the student must know to attend to airspeed, bank angle, altitude, and vertical speed. If the student notices that altitude is decreasing, he must add power (increase RPM to 2250), and adjust the elevator trim to restore the aircraft to a level flight turn. BFITS monitors the appropriate variables and provides guidance in the form of hints or messages that warn the student when variables exceed tolerances.

Attempting to monitor many variables and give the pilot hints introduced some problems beyond the capability of the performance monitoring program. For instance, if the airplane is at a desired altitude and the vertical speed indicator begins to show a climb, the hint screen would give the appropriate message of "You're climbing! Check your pitch and power." But, if the airplane is below the desired altitude the hint screen might say "Altitude low. Should be 3000 feet." When the pilot begins a climb back to the desired altitude the message "You're climbing! Check your pitch and power" is inappropriate because the pilot is making a proper correction back to the desired altitude.

An on-board instructor would know when the climb hint is appropriate and when it is not. The Flight Criteria program is basic in that it does not have the logic built in to apply the If-Then logic that is appropriate. If below altitude, then climbing is permissible; if at desired altitude, then climbing is not desired. Similar logic problems arise in the monitoring of flight variables while the airplane is following a desired ground track.

The logical inconsistencies could be avoided in two ways: (a) by adding a built-in logic system or (b) by monitoring only the primary variables, giving hints when they stray, and to not give hints when the secondary variables start to deviate with the potential of having excessive error in a primary variable. It was felt that the former was too cumbersome for the system as it was configured. The latter was implemented and has proven a suitable approach at this early stage. This should be kept in mind in any future validation studies.

A record is made of all answers given by the student, along with various flight data (see Table 2). This record can be utilized initially for the improvement of BFITS (i.e., checking to insure that the materials were presented well and that the questions were not vague or misleading).

This record should allow the researcher to construct a lesson history indicating the items a student missed, which sections he/she was required to review, how much time was spent reviewing these sections, and so forth. Additionally, this data will aid in the formative evaluation of the lessons and the overall program.

Simulator Module Design

The initial hardware specification dictated that the runtime system would be a Zenith Z-248 with EGA, 20 megabyte hard drive, math coprocessor, 640K plus 2 megabytes of extended memory. This has been the standard system in the LAMP (Learning Abilities Measurement Program) laboratory for several years. The LAMP laboratory is in the process of acquiring Desktop 3 systems; these will be the standard platform for future LAMP and BFITS testing.

The initial development of BFITS was performed using various systems (Z-248, Z-286 LP, Compustar, IBM PS/2 Model 30, and others). The relative value of the data to be collected by the BFITS systems was significantly influenced by the lack of similarity in computer systems and the corresponding variations in simulation update rate. It was decided that the best solution was to standardize the computer systems being used. To provide for an easy transition to the Desktop 3 systems, five standardized hardware kits were acquired which allowed processor upgrade to a level of performance comparable to that of the Desktop 3.

<u>Table 2.</u> Logged data

Question Response Data:

- Response latency.
- Correct responses.
- Incorrect responses.
- Incorrect response specifics.
- All scores.

Comprehensive Practice Flight Data:

- Aileron position
- Elevator position
- Rudder position
- Engine RPM
- Flap position
- Bank
- Pitch
- Heading
- Altitude
- Air speed
- Vertical speed
- Rate of turn
- Ball position
- World x and z coordinates
- Segment number
- Trial number
- Step number

Also acquired for this effort were 40 Simulator Accessory Kits. These include a Joystick (CH Products' FlightStick), joystick interface (a standard gamecard), and a custom rudder pedal assembly. These devices allow full control of simulated aileron (with trim), rudder, elevator (with trim), and throttle.

A complete description of hardware requirements is included in the system documentation. Any potential system user should be aware that the BFITS system has been designed for operation on Desktop 3 (or equivalent) systems. Use on other hardware may or may not result in reliable operation and accurate flight simulation behavior.

The simulator has been designed to replicate the characteristics of a generic training aircraft. The performance characteristics of the C-172/T-41 trainer were used as a baseline in developing simulator characteristics. The flight model was designed in-house after a search for existing flight models was conducted through both the Defense Technology Information Center (DTIC) and the Federal Laboratory Consortium Clearinghouse. Table 3 lists the major flight relationships included in the BFITS simulation flight model.

Many aircraft flight dynamics are defined within a data table, allowing changes to the flight model to be made with a minimum of effort. Most of the software has been developed using Pascal and industry-standard modular programming techniques. Some real-time graphics functions have been implemented using assembly language to increase system speed and performance.

External simulator features include display of the "sacred six" flight instruments (airspeed, attitude, altimeter, vertical speed, heading, and turn and bank indicator), plus flap indicator, navigational radio equipment, engine instrumentation, and out-the-cockpit view. Position indicators are provided for the aileron, elevator, and rudder.

Table 3. BFITS flight model relationships

Rudder / Bank effect
Aileron / Bank effect
Rudder / Yaw effect
Aileron / Yaw effect
Power / Yaw effect
Elevator / Pitch effect
Power / Pitch effect
Aircraft Roll Stability
Pitch Stability
Bank / Rate of Turn effect
Pitch / Rate of Turn effect
Rudder / Rate of Turn effect
Engine Thrust Effect
Airframe Drag
Angle of Attack effect on Thrust (Drag)
Aircraft Weight
Power contribution to lift
Angle of Incidence
Wing Lift capability as a function of AOA
Stalling Angle of Attack
Stall Clean (VS1)
Stall Dirty (VSO)
Flap effect on Pitch
Flap effect on Thrust (Drag)
Airframe Service Ceiling
Engine Service Ceiling

The out-the-cockpit view has several unique features. The standard field of view is 25% greater than would normally be provided. The size of the images in displays of the outside world has been found to have a significant influence on a pilot's ability to perform landings and takeoffs. Roscoe (1948, 1951) and Roscoe, Hasler and Dougherty (1966), using a projection periscope in a Cessna T-50 airplane, found that landings were most accurate in terms of both constant and variable errors using an image magnification of 1.25. Roscoe's results were confirmed by Campbell, McEachern, and Marg (1955) using a binocular periscope for approach and landing. Because of these findings, the out-the-window view in the BFITS simulator was changed to have a magnification of 1.25 as opposed to the original 1.00.

A second magnification level of 3.00 has also been provided. Since there are no "side windows" available, this method allows earlier detection of the runway and airport environment when flying traffic patterns. Toggling between the standard magnification (1.25) and the wide-angle magnification (3.00) is performed with a press of the "V" (for view) key. The outline of the standard view perimeter is provided when using the wide-angle mode as an indication that the mode is active and to assist in deciding when to switch back to standard mode.

An *overhead* view may also be superimposed over the right side of the out-the-cockpit view. This provides a simple means of maintaining orientation to the runway when it is not within either field of view. It allows the pilot to maintain runway / aircraft orientation while circling the airport traffic pattern. It also assists in the instruction of crosswind correction techniques and ground tracking. A similar overhead view is provided for use in learning turns around a point.

The actual simulator environment includes the runway, buildings, roads, mountains, and trees. The runway includes Visual Approach Slope Indicator (VASI) lighting and centerline markings. Roads and terrain features can be used in learning crosswind correction techniques and as external heading references. Trees and buildings provide both lateral motion cues along with height information essential to proper landing techniques. A moderate density of simple objects in the visual field has been achieved in lieu of high fidelity. Kleiss, Hubbard, and Curry (1989) demonstrated that this level of fidelity to be effective in flight training tasks.

The design of the simulator was guided by the need to track, respond to, and evaluate student performance while flying against specified levels of criteria. A general flight format was developed as shown in Table 4.

Segments can be thought of as *frames*. By associating a particular goal (Climb, Turn, Landing, etc) with a frame, an instructor can quickly create a new flight task (such as a climbing left-hand turn in slow flight) by simply combining a number of segments. The instructor does this by using an editor. The editor was developed to allow creation and easy modification of the flight criteria. There are context-sensitive help facilities, multi-windowing, error messages, automatic dependency checking, and a host of copy, delete, and move options. Any changes to existing flight criteria are detected, and the user is asked if he/she wants to

Table 4. Flight Format

A statement of the flight/lesson objective
A demonstration by example of the desired performance
Guided practice (real-time feedback)
A review of each maneuver noting criteria being evaluated and actual student performance.
Continuation of practice until the criterion level of performance is attained.

The term *flight criteria* is used to denote the block of information that is passed to the simulator, and in essence, defines the student flight task. The flight criteria are arranged in a hierarchy (see Figure 2). Each level in the hierarchy is more fine grained than the level above. This structuring allows for rapid task setup and modification, automatic task control, and real-time student evaluation with minimal overhead. A flight test may consist of a number of tasks. For example, the flight test in lesson 10 involves a climb, straight-and-level flight, and a descent. Each of these tasks is associated with a *segment*. Thus in lesson 10 there are 3 segments. Tasks are divided into sub-tasks, each corresponding to a *step*. The climb segment in lesson 10 is made up of 5 steps. Associated with each step is a group of variables that define the sub-task and trigger sequential transitions from one task to another. The variables are also used to in student flight performance evaluation.

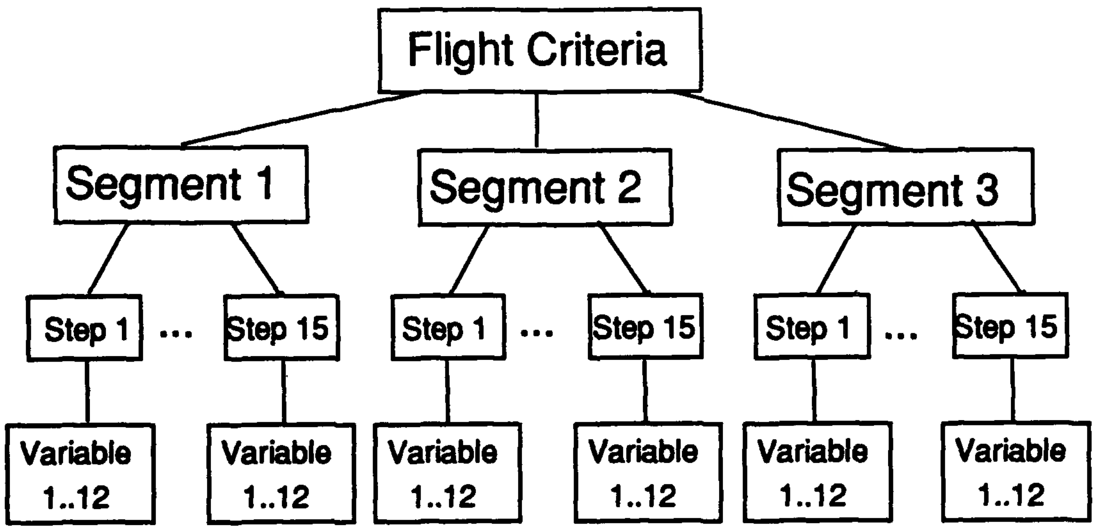


Figure 2. Flight Criteria Hierarchy

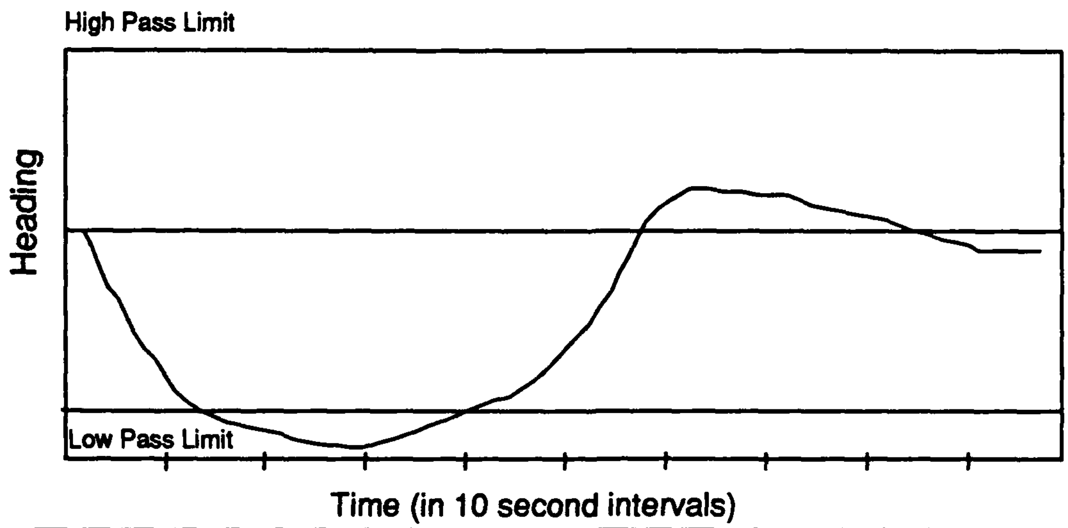
create a new version. By responding yes, a new version is automatically created and the previous version is saved to disk.

The simulation begins with an explanation of the flight objectives and a demonstration flight. Pressing one of the joystick buttons initiates the student test flight. During the flight, the student's progress relative to the stated objective is constantly monitored. If the student begins to deviate from the expected flight parameters, he/she receives hints relevant to the area of deviation. For example, if the altitude must be maintained and the student begins to climb, a message would appear on the screen saying something like "You're starting to climb. Level off." At the same time, the student's performance is being evaluated on a pass / fail basis. At the end of a flight, a student can look at a statistical review of the flight, (see Figure 3). If the student desires even more information regarding his/her performance on the prior maneuver, a playback of the last performance can be selected. This will present the entire maneuver as the student flew it, and the hint window will indicate when the desired parameter limits were exceeded. So, not only does the student see the maneuver that was just flown, but is told when and where the limits of desired performance were exceeded.

Variable: Heading in degrees

Step: Level off   Segment: Climb

Target	High Pass Limit	Low Pass Limit
300.00	310.00	290.00
Average	**High**	**Low**
292.54	302.5	288.00



Esc-exit graph	Arrow keys-view a new variable	Trial#: 2

Figure 3. Review Screen

The student is not allowed to continue with later flight tasks until all preceding flight tasks have been successfully completed. (See Figure 4).

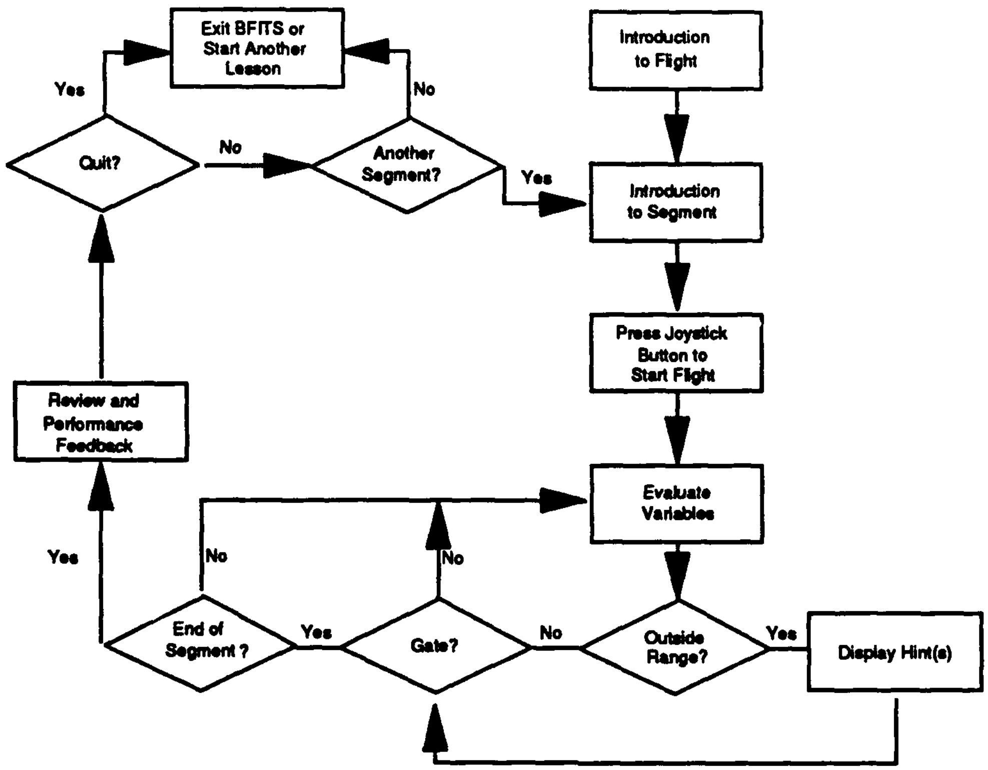


Figure 4. Simulator Flow

A key concept in BFITS task control is that of a *gate set*. This is the mechanism that moves the simulated flight task from beginning to completion. The gate set consists of a gate, evaluation criteria, and an implicit transition. The gate is a value describing a discrete state for a particular flight variable (see Table 5).

Table 5. Flight Variables

1. Bank
2. Heading
3. Altitude
4. Vertical Speed
5. Air Speed
6. RPM
7. Pitch
8. Rate of Turn
9. Ball Position
10. Position East-West
11. Position North-South
12. Time
13. Flaps

The performance evaluator examines simulator states in real-time, logically evaluating the current value of the flight parameter and its associated gate value. Transitions occur when the evaluation is true. The transitions are implicitly defined in terms of the truth evaluation of a gate. This is what moves the flight task along. Student feedback and evaluation also occur in real-time, under the management of the evaluator. For a particular flight parameter, a range is specified around a base value for both pass/fail evaluation and instructor feedback. The feedback takes the form of hint messages being displayed on the screen. For example, Figure 5 shows the flight criteria for the first flight task of lesson 10. The box surrounding the characters EG in column 2 and in the same row as Altitude can be used to select any variable within any step. This example indicates that a Gate Value equal to or less than 2000 feet has been assigned to the flight variable Altitude for step 2. Also visible are Step and task titles. The Segment title indicates that this is a descent. The student initiates the flight by pressing the button on the joystick. Pressing the joystick button is the default gate when beginning a new segment, and causes the simulation to transition to step 2. The simulator then begins to monitor the altitude and when it equals 2000 feet or less, the simulator state transitions to step 3.

SEGMENT # 01	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Bank	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Heading	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Altitude	IG	$\boxed{\text{EG}}$	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Vertical Speed	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Air Speed	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
RPM	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Pitch	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Turn	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Ball Position	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Ground Track	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Time	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG
Flaps	IG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG	EG

Gate Value <=2000	Step Title: Descent	Seg Title: Descent
Baseline	Hi	Lo
Hi Hint	Lo Hint	
Hi Hint Lo Hint Hi Recap Lo Recap		

Lesson 10 Ver 001 Seg File Intro Esc-Quit <-|->-Choose <- Edit F1-Help

Figure 5. Flight Criteria for Segment 1, Lesson 10

CONCLUSIONS

1. BFITS is the first known PC-based flight simulator system to train subjects to perform such a wide variety of maneuvers from basic to traffic patterns with crosswinds, and require a minimum level of performance for progression and successful completion. BFITS can be easily modified to change the variables monitored and the tolerances of acceptable performance. New maneuvers can be developed, if required, using an experienced flight instructor to develop adequate flight criteria for the evaluation of performance.

2. If different populations are used, the criteria can be changed. In fact, many versions of the flight criteria can be developed, with the researchers or instructors selecting the appropriate version of the criteria for the individual subject using the system at that time.

3. BFITS was not intended to be the ultimate computer-based flight instructor, but it is comprehensive and has face validity with regard to potential transfer of training to actual aircraft performance. Its predictive validity in that area must be determined.

RECOMMENDATIONS

Although BFITS has been reviewed by many persons during its development, it is likely that its instructional effectiveness can be improved through further research. For example, the content of BFITS lends itself well to different types of illustrations (Mayer & Gallini, 1990) and models (Mayer, 1989). Further research could investigate the effects of different types of illustrations and models on declarative learning. Flying skill development on BFITS might also be enhanced with digitized voice technology, and diagnostic feedback after each flight session. We are concerned that the on-line hints now presented in printed form on the screen, may put the less-skilled reader at a disadvantage. Digitized voice technology could be used to present these hints, perhaps more effectively for the less-skilled reader.

The second enhancement, diagnostic feedback, might require a more substantial research and development effort. The basic idea is to tell student pilots after each flight what they have done incorrectly and how they might improve their performance. Student flight data might be compared to prototypical mistakes made by student pilots. If a student's data matches a prototype sufficiently well, the computer might then provide guidance about what to do differently when performing the maneuver. Diagnostic feedback requires prototypical mistakes, a means of collecting and representing them, and a pattern-matching algorithm for diagnosis. Expert flight instructors could be asked to simulate common student errors on a given maneuver using BFITS. Developing a pattern-matching algorithm would be a significant technical challenge, but one possible approach would be to compare the student's profile of flight criteria to the mean profile of flight criteria obtained from the flight instructors.

Although the flight criteria used by BFITS are similar to those used by the FAA in the administration of the practical flight tests for the private pilot certification, the adequacy of the flight criteria for a population of flight-naive students using BFITS remains to be determined. After all, the BFITS flight simulator is not quite the same as an airplane.

After a trial run with a small sample, BFITS should be administered to a significant number of flight-naive subjects to obtain normative data on the test items and flight skills development. Where possible, measures of the transfer-of-training capability of BFITS into a flight training program should also be obtained.

The first generation BFITS should be an effective research tool for investigating the acquisition of flying skills. We see additional applications for BFITS in assessing the effects of drugs, stress, and other environmental factors on pilot performance.

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